International Ice Patrol's Iceberg Sighting Data Base 1960-1991

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Introduction

International Ice Patrol has been actively collecting iceberg data in the vicinity of the Grand Banks of Newfoundland and off the coasts of Labrador and Greenland since 1913. This paper concentrates on the period from 1960 to present. The objectives of this paper are to describe the iceberg sighting data for the period 1960 to the present, describe how the data was collected, the limitations of the data set, and what the data set represents.

In 1984, Ice Patrol placed all available historical iceberg sighting information from the original paper records into a computerized format. The data covered the period from 1960 to 1982. The original sighting information from the period prior to 1960 was no longer available. Summaries of the sighting information prior to 1960 are contained in the International Ice Patrol bulletins (Alfultis, 1987). For example, recently the scientific community has shown a renewed interest in the International Ice Patrol's iceberg sighting database. This interest has been spurred by the growing research into global warming and a renewed interest in hydrocarbon production off the Grand Banks of Newfoundland. Marko et al. (1991) and Davidson, et al. (1986) have used the Ice Patrol database as part of their research. There have also been numerous efforts to predict the severity of the seasonal variations of icebergs off Newfoundland (Examples: Schell (1961), Ebbesmeyer, et al. (1980), Davidson, et al. (1986), and Walsh (1986)). The cautious reader might consider a review of Kinsman (1957) before applying the Ice Patrol database to another geophysical problem.

The above studies have all used the Ice Patrol data as the basis of their studies, but there is a weak recognition of the subjectivity of the Ice Patrol data set. Few authors have considered the importance of the subjectivity, the implications of changing technology, or most importantly, the nature of the Ice Patrol mission itself. Although Davidson, et al. (1986) have more appreciation than most of the complexity of the data set, even they do not consider the significance of the nature of the IIP mission itself.

The International Ice Patrol Mission

The U.S. Coast Guard conducts the International Ice Patrol Service in the North Atlantic under the provisions of U.S. Code, Title 46, Sections 738, 738a through 738d, and the International Convention for the Safety of Life at Sea (SOLAS), 1974, regulations 5 through 8. The above stipulate that the International Ice Patrol Service be maintained "during the whole ice season in guarding the southeastern, southern, and southwestern limits of the region of icebergs in the vicinity of the Grand Banks of Newfoundland, and the patrol shall inform trans-Atlantic and other passing vessels by radio and such other means as are available of the ice conditions and the extent of the dangerous region."

The philosophy of Ice Patrol aerial reconnaissance to accomplish the mandated mission was described in the 1960 Ice Patrol Bulletin. The philosophy as stated then and repeated below holds true for the entire period covered by this paper. "Search areas are determined by the degree and reliability of available ice information over the Grand Banks, prevailing weather conditions of wind, sea, and visibility, and the activity of the Labrador Current. The primary objective (of Ice Patrol's aerial reconnaissance) is to maintain accurate information concerning the southwest, southern, and southeastern limits of the ice. A secondary objective is to fix the location of as much of the ice within the limits as is consistent with the accomplishment of the primary objective." Using the above philosophy as the basis of accomplishing its mission, Ice Patrol does not and has never attempted to conduct a complete census of the icebergs or survey the whole of the Grand Banks for icebergs. The presence or absence of icebergs in areas removed from the extreme limits of the region of iceberg danger does not affect the performance of the Ice Patrol mission. Generally, areas of the Grand Banks removed from the limits of iceberg danger can have significant concentrations of icebergs and because of the nature of the mission; the icebergs located there may not be included in the data set.

Iceberg Data Collection

The traditional measure of an iceberg season's severity is the estimate of the number of icebergs drifting south of latitude 48 North. The methods used to collect and analyze the data have changed over the years. In addition to changes in methods, a variety of factors affect the accuracy of the estimate published each year. These include the use of numerical models, the severity of the season itself, reconnaissance techniques and technological advancements, subjectivity caused by change in personnel, and navigation accuracy. A summary of the technological changes is included in FAQ 24. These factors will be discussed in more detail below.

The reason for selecting 48 North as the boundary at which to begin counting icebergs is tied to the great circle shipping routes from Europe to America. The great circle route from the English Channel to New York would pass through the island of Newfoundland so the routes used had a turn point off Cape Race, the southern point of Newfoundland. Cape Race is located at about 46 degrees 35 minutes North. Early reports of the International Ice Patrol Service (prior to 1926) refer to icebergs south of Newfoundland. Mecking (1907) collected data from U.S. Signal Service, U.S. Hydrographic Office and the Deutsche Seewarte (the German Hydrographic Office) and published the first estimate of icebergs for the period 1880 to 1897. Smith (1926) continued the analysis and published the estimate of icebergs for the period 1898 to 1926 and used the 48th parallel as the northern point of his analysis. IIP has published the 50 yearly estimate of icebergs drifting south of 48 North in the annual Reports of International Ice Patrol Service ever since (FAQ 7).

Presently, International Ice Patrol does not include sighting reports of growlers or radar targets in the estimate of the number of icebergs drifting south of 48 North. Radar target reports (targets which cannot be identified) come from a variety of sources including ships and aircraft. Therefore, this paper does not include radar targets or growlers as part of the discussion.

General

The present Ice Patrol operations area is bounded by the area 40 to 52 North and 57 to 39 West (FAQ 14). Ice Patrol's statutory mandate requires Ice Patrol to define the limits of the dangerous region, not survey the entire area where icebergs might exist. Ketchen (1977) provides a synopsis of icebergs sighted well outside of the Ice Patrol operations area. Although these are dramatic sightings because of their extraordinary location, they represent only a small fraction of the icebergs seen in most years. The area encompassed by the limit of the iceberg danger fluctuates on a season-to-season basis and also within a season. Traditionally, the portion of the Ice Patrol operations area enclosed by the limit of iceberg danger is largest during the months of April through June within each season. There have been seasons where the area of iceberg danger has extended south of 40 North, the southern border of Ice Patrol's normal operations area. When this occurs, Ice Patrol's reconnaissance efforts are concentrated in the southern area because Ice Patrol is not able to use the available model to predict the movement of icebergs in this area. This last occurred in 1989.

The available reconnaissance flights are first used to fly the edge of the area of iceberg danger (where the iceberg concentration is low) to accurately define the limits of iceberg danger. The more available flight time spent in transit to reach extended limits means proportionally less of the limit of iceberg danger that can be covered per flight. Therefore, more flights are required to cover the whole of the limits leaving less time to cover interior areas. When the area encompassed by the limits of iceberg danger is large, the potential for Ice Patrol reconnaissance to sight icebergs is reduced. The further north in the Labrador Current reconnaissance is conducted, the higher the density of icebergs. When all reconnaissance flights are dedicated to flying along the limits to define the area, the potential coverage of the interior is greatly reduced and the potential for icebergs to drift south of 48 North in the Labrador Current and never be sighted increases. **The lack of interior coverage does not affect Ice Patrol's ability to fulfill its mission but it does affect Ice Patrol's annual report of the estimate of icebergs that drift south of 48 North.**

Ice Patrol Reconnaissance (1960-1982)

Ice Patrol conducted visual aerial reconnaissance during this period. On an as needed basis, surface patrol craft, supplemented aerial reconnaissance. The surface patrol craft's duty was to stand by the southern most iceberg and report its position to shipping and Ice Patrol headquarters. When it melted, the patrol craft would locate and remain with the next most southern iceberg. Surface patrol craft were used only during the 1972 and 1973 seasons. Vessels capable of conducting oceanographic work were deployed to the Ice Patrol operation area to conduct oceanographic research for many of the years covered by this report. These vessels were not considered surface patrol craft but did report the positions of observed icebergs. Neither the surface patrol vessels nor the research vessels contributed substantially to the number of iceberg sightings.

During the period from 1963 to 1982,Ice Patrol made iceberg survey flights north along the Labrador coast up into Baffin Bay. The iceberg sighting data from some of these flights are included in the digital database. The information entered into the database does not represent the complete set of sightings received by Ice Patrol from these flights. Only the data contained in the retained Ice Patrol paper records was entered into the database.

These flights were used to get an early indication of the upcoming season's severity and therefore did not affect the estimate of icebergs crossing 48 North.

Coast Guard aircraft were deployed and available at a Canadian base of operations throughout the season. ln l962, the HC-130 (B model) was introduced as the aircraft for Ice Patrol's mission replacing the R5D (average patrol length 1200 miles). The HC- 130 was a longer-range aircraft allowing more area to be covered in a single flight. The B model ice reconnaissance flights averaged about 1500 miles in length, including transits to and from the search area. In 1981, the HC-130H model was introduced into service with Ice Patrol. This model had about 20 percent more range (average flight track length of 1800 miles) than the B model. With each increase in range, the aircraft covered more area increasing the possibility of detecting more icebergs during a single flight.

From 1960 to 1970, Ice Patrol reconnaissance aircraft were based out of Argentia, Newfoundland. A permanent Coast Guard aviation detachment was stationed in Argentia with several aircraft at their disposal. This allowed for more than one aircraft to fly ice patrol reconnaissance flights to different areas on the same day when the weather was good. In 1970 with the closing of the U.S. Naval Air Station at Argentia, Ice patrol moved its base of operations to the Canadian Forces Base at Summerside, Prince Edward Island. The one aircraft used by Ice Patrol was deployed from Coast Guard Air Station Elizabeth City, NC and not permanently stationed in Canada.

The move from Argentia to Summerside greatly increased the time required to make the transit from the operating base to the iceberg search area. The increase in transit corresponded to a decrease in search time (and area) for icebergs. During periods when good weather was forecast, the aircraft would remain overnight in St. Johns, Newfoundland reducing the transit time to the search area.

In 1974, the Ice Patrol base of operations for aerial reconnaissance was moved from Summerside to St. Johns. The base of operations remained in St. Johns through the end of the 1982 season. This change in operating locations reduced the transit time to reach the selected search areas. Occasional poor terminal weather conditions (fog) at St. Johns reduced the number of potential available reconnaissance days. A high percent of the poor terminal conditions days also directly reflected poor weather in the search areas. During the visual reconnaissance period, weather, both at the search area and the terminal, was a primary factor in iceberg reconnaissance flight planning. Fog is prevalent on the Grand Banks during the period of about mid-April through early July. The aircraft generally flew their patrols at an altitude of about 1,000 feet with a track spacing of 25 nautical miles. If the terminal weather conditions were acceptable for takeoff and return, a flight was planned for an area of the boundary of all known ice where the weather was good. Good weather on scene was defined as having visibility forecast for over at least 50 percent of the planned search area. From 1960 to 1982, an average of about one flight was conducted every 4.5 days during the season. Non-flying days were due to bad weather and aircraft mechanical problems. Occasional flights to the interior of the limits were also conducted. Occasionally fights to the same area on consecutive days would be flown to evaluate radar targets detected on the previous day's flight.

During the years 1960 to 1968, the percent of the area flown that was able to be effectively searched visually (where cloud cover was less than five tenths) was published in the annual Ice Patrol Bulletins. On an average, only 70 percent of the area flown was able to be searched visually. **This means icebergs possibly existed undetected within the search area.**

During the early and mid-1970s, Ice Patrol mostly used pre-set flight plans to cover specific sections of the operations area. Information about these preset flight plans can be determined by reviewing the flight plans published in the Ice Patrol Bulletins for that period. If needed, a non-standard flight would be flown.

In 1960, the only electronic method of navigation available to the Ice Patrol aircraft was LORAN-A. In 1964, Doppler navigation equipment was installed on the aircraft. The LORAN-A coverage of the Ice Patrol operations area was limited and Doppler improved the navigation accuracy. In 1973, an Inertial Navigation System (INS) was installed on the Ice Patrol aircraft. In the early 1990's, Global Positioning System (GPS) became available and was installed IIP aircraft. INS and GPS are presently the primary navigation systems on the aircraft used by Ice Patrol. INS did not require the receipt of an external signal and greatly improved the navigational capabilities of the aircraft. The cumulative error for the INS over an Ice Patrol is on the order of 10 nautical miles. GPS fix accuracy is less than 1/2 nautical mile. Each improvement in the navigation capability of the patrol aircraft meant the aircraft could fly the planned patrol area more accurately with less gaps in the area coverage caused by navigational errors. The improvements also meant the iceberg position reports were more accurate.

Ice Patrol Reconnaissance (1983-Present)

1983 saw the introduction of the APS-135 Side Looking Airborne Radar (SLAR) aboard the assigned HC-130H model aircrafts the primary iceberg detection tool, supplementing the human eye. This instrument had a profound effect on Ice Patrol's reconnaissance operations. The SLAR provided a near all weather target detection capability. It also changed our reconnaissance strategy, including aircraft deployment scheduling.

Beginning as early as 1957, the International Ice Patrol had began evaluating a variety of SLARs. Although a variety of testing and evaluation was conducted, no SLAR was used on a continuous, operational basis prior to 1983. Ice Patrol used the results of the limited SLAR research flights as input into the drift prediction model, however these targets were not differentiated from visual sightings. These research flights did not contribute significantly to the number of sightings.

In 1983, SLAR became an integral part of Ice Patrol's routine reconnaissance operations. The SLAR equipped aircraft conduct patrols at 6000-8000 feet. The flights were flown with a 25 nautical mile track spacing. The SLAR range used is 27 nautical miles (50 kilometers). This SLAR range combined with the track spacing allows for about 200 percent coverage of the interior portion of a standard parallel leg type search (Figure 3). Moderate or greater turbulence and moderate or greater precipitation reduces the SLAR's ability to detect targets. Flights are planned to avoid both of these factors. Flight cancellations due to poor on-scene weather conditions were greatly reduced with the introduction of SLAR.

Also in 1983, Ice Patrol moved its base of operations from St. Johns to Gander, Newfoundland. In 1988, Ice Patrol returned its base of operations to St. Johns. Both of these moves had little effect on Ice Patrol operations. Although St. Johns is a little closer to the southern portion of the area of iceberg danger, the small increase in flight transit time and corresponding decrease in search area had a minimal effect on Ice Patrol reconnaissance efforts.

The use of SLAR drastically altered the Ice Patrol aircraft deployment schedule. Instead of having an aircraft deployed to Canada on a continuous basis during the ice season, a SLAR equipped aircraft was deployed for a one-week period every other week. With SLAR, Ice Patrol was able to conduct a similar number of flights and increase the coverage of the operations area. Transit legs to and from the search area could be searched with SLAR, increasing area coverage per flight. During the visual flight era, the transit legs were flown at altitude, generally above the clouds and very few iceberg sightings were recorded. The change in aircraft deployment schedule placed a larger reliance on Ice Patrol's iceberg drift and deterioration prediction models. Research efforts during the period 1986-1988 focused on evaluating the model performance. The results indicted, with good environmental input, the models performed within acceptable error tolerances (Murphy and Anderson, 1985, and Hanson, 1987).

Research was conducted in 1984 and 1985 to evaluate the APS-135 SLAR performance. The results indicated the SLAR was a very capable iceberg detection tool (Rositter, et al., 1985 and Robe et al., 1985).

In 1989, the HU-25B Falcon jet equipped with an APS-131 SLAR was first used as an Ice Patrol aerial reconnaissance platform. The APS-131 SLAR also provides a near all-weather target detection capability. There is only one central antenna pod on the Falcon with the antenna being half as long as the antenna on the HC-130. The HU-25B is a much smaller airframe and is more susceptible to being rocked by air turbulence. On a turbulence free flight, the detection capability of the APS-131 SLAR is similar to that of the APS-135 SLAR (Alfultis and Osmer, 1988). The Falcon's range of 700 nautical miles is considerably less than the HC-130 and thus it is not capable of reaching and then searching the limits of iceberg danger during the peak of the season. The HU-25B is generally only used near the beginning and end of the season and is deployed in place of an HC-130 as part of the same every other week schedule. The HU-25B flies two three-hour sorties per day compared to one seven-hour sortie for an HC-130. The total area covered per day by the HU-25 is considerably less than the HC-130. Due to its limited range, the HU-25B has not been used extensively.

Along with SLAR's operational benefits came an important problem, target discrimination. When unable to see the surface, the operator must decide whether the target detected is an iceberg or not. Farmer (1972) provides a general overview of why SLAR is a good iceberg detection tool and a description of the visual cues used to classify SLAR targets. On the basis of this study, Ice Patrol decided to make identifications without seeing icebergs using the available cues. The cues on the film aid the experienced operator in determining the identification of some targets. When two looks at the same target from different legs of the search pattern are available, movement or lack of movement of the target is a particularly useful tool in deciding if a target was an iceberg or not. For targets without any cues, the operator's ability to discriminate between an iceberg and a vessel correctly is only just above chance (Thayer, 1985).

During the first several years use of the SLAR, the operators were learning how to use the available cues to discriminate between vessel and iceberg targets. This target discrimination problem effects Ice Patrol's estimate of the number of icebergs drifting south of 48 North. During the first several years of SLAR use, it is probable that some of the targets identified as icebergs from the SLAR were not icebergs but fishing boats. Although the estimate of the number of icebergs drifting south of 48 North may have been effected, the 1983-1985 seasons would still remain classified as extreme. As Ice Patrol's experience with the SLAR increased, the probability of the operator wrongly identifying a target has been reduced but not eliminated.

In light of the target discrimination problem, visual confirmation is still sought for icebergs that set the limits of the area of iceberg danger. Flights are planned during the deployment period to make the best use of available visibility.

See Database Updates Since 1991

Other Sighting Sources

The estimate of the icebergs south of 48 North is made from all data collected and analyzed by Ice Patrol throughout the year. Ice Patrol actively solicits other reporting sources to supplement Ice Patrol's own data gathering efforts. Ice Patrol relies on reports from commercial shipping to help improve the quality and accuracy of the products delivered to the maritime community. As an example, in 1991 reports from shipping accounted for over 50 percent of the icebergs entered into the drift prediction model. Throughout the period covered by this paper, other sources of iceberg sighting reports have been added. With the addition of each new source, the potential for increasing the annual estimate of the icebergs drifting south of 48 North increases, particularly when the new source's efforts are concentrated in areas not otherwise fully covered.

The sighting source for icebergs was recorded as one of three types from 1960 to 1981. The three source categories used were USCG aircraft, USCG ship report, and other USCG vessels transiting to and from ocean stations in the North Atlantic and vessels performing oceanographic research on the Grand Banks for Ice Patrol provided the sighting reports recorded under this category. Examples of reports received within the "other" category includes commercial shipping reports, reports from commercial, U.S., and Canadian military aviation, and reports from lighthouses. Between 1981 and 1983, the sources of sighting reports entered into the drift model were not recorded and are now no longer available. In 1984, a ten-category sighting source code was added to the drift model as part of the data entry procedure.

In the early 1980s, the Canadian Atmospheric Environment Service (AES) began flying dedicated iceberg reconnaissance flights. Funding for this program has varied and the number of reports received is directly proportional to funding. The AES iceberg reconnaissance efforts to date peaked during the 1987 and 1988 seasons. AES used an APS-94E SLAR as the primary iceberg sensor on their Electra patrol aircraft through 1990. The APS-94E was evaluated in 1984 and its detection capability was less than the APS-135 (Rossiter, et al., 1985). In 1988, a DASH-7 with a CALSLAR was introduced into service by AES. The AES iceberg flight efforts within the Ice Patrol model area are concentrated near the sea ice edge within the Canadian exclusive economic zone. There ice edge is within the area of higher iceberg density. AES iceberg dedicated flights emphasize visual searches. AES reports SLAR targets that are not visually confirmed icebergs as radar targets. In about 1984, Ice Patrol began to receive iceberg reports through the NOAA/U.S. Navy Joint Ice Center (now National Ice Center). The information comes from a variety of Department of Defense sources and is passed to Ice Patrol for entry into the dhft prediction model. The sighting reports are spread throughout the model area. In 1986, this source accounted for an all-time high of 11 percent of the icebergs entered into the model.

In the 1980s, exploratory efforts to develop the hydrocarbon resources on the Grand Banks began. The Hibernia oil field area lies between about 46 North to 49 North on the eastern portion of the Grand Banks. The Canadian government regulations' concerning drilling requires the operators to conduct surveillance for icebergs in their exploration area. Beginning in about 1985, the sightings made by the hydrocarbon industry were voluntarily supplied to Ice Patrol. This period of activity only lasted about 4 years and led to an increase in the number of sighting reports in the area of the Hibernia oil field and affected the value of the estimate of icebergs crossing 48 North for those years.

In 1989, the sighting source code used for the hydrocarbon industry was renamed "Other aerial reconnaissance." This category now includes iceberg sightings received from the Canadian Department of Fisheries and Oceans (DFO). DFO contracts flights to conduct reconnaissance of foreign fishing vessels activity on the Grand Banks. The contractor supplies reports of the icebergs and unidentified radar targets seen on each flight to Ice Patrol. The fishing activity is concentrated along the shelf break of the Grand Banks and Flemish Cap, areas of potential high iceberg density. The number of flights conducted by the contractor increased in about 1991 with a commensurate increase in the number of iceberg reports.

The sighting code used by the model was changed in 1989 to accommodate a new source of icebergs. The AES iceberg Analysis And Prediction System (BAPS) models iceberg drift in an area to the north of Ice Patrol's model area. AES supplied the predicted positions of those icebergs which were predicted to have drifted across 52 North and Ice Patrol entered them into its model. This particular source did not affect the estimate of icebergs drifting south of 48 North because none of these icebergs reached 48 North prior to either melting or being resighted by another source closer to 48 North.

Modeling Of Iceberg Drift

The Ice Patrol models described below were operated only during the portion of the year of iceberg danger. Generally, this would be about one month on both sides of the period when Ice Patrol daily bulletins were issued. This means that reports of icebergs received outside of this period may not have been included in the annual estimate of the number of icebergs crossing 48 North.

Modeling Of Iceberg Drift (1960-1971)

From 1960 to 1971, Ice Patrol maintained a hand plot of the iceberg's predicted motion. Ice Patrol used vector addition of the effects of the wind and sea current on icebergs to predict their motion. The exact origin and basis of this technique was not recorded but was based upon research conducted by Ice Patrol since its inception. The wind component vector was computed as the down wind direction plus 50 degrees to the right (to include the effects of coriolis) with a magnitude of drift (in miles/12 hour period) of .003684 x W x W + .282 x W (where W = wind speed in knots) (Morgan, 1970). This portion of the drift component was to take into account leeway and the Ekman current component. The coefficients of the equation were adjusted over the years. The above coefficients are from the late 1960s.

The wind data for the vector addition routine was obtained from the U.S. Navy Meteorological office at Argentia until the closure of Air Station Argentia in 1970. After 1970, the wind data was supplied by the U.S. Navy Fleet Numerical Weather Center (FNWC) in Monterey, the predecessor of the Fleet Numerical Oceanographic and Meteorological Center (FNMOC).

The ocean current information was derived from two sources. Ice Patrol conducted hydrographic surveys in the vicinity of the Grand Banks beginning shortly after the inception of Ice Patrol and developed geostrophic current data using the methods described in Sverdrup et a, 1942. Monthly mean dynamic heights for the area of the Grand Banks were developed (Soule, 1964). The U.S. Navy Oceanographic Office monthly mean charts of sea current were used to provide information for the area outside of that covered by the Ice Patrol mean dynamic height charts. The sea current was vectorially added to the wind component to predict iceberg drift.

With a manual plot method, there was a practical limit to the time available to predict the drift of icebergs upstream of the icebergs closest to the area defining the limit of all known ice. During light iceberg years, it was possible to predict the drift of all of the icebergs reported to Ice Patrol. During a heavy iceberg year, it may have been impractical to predict the drift of all the reported icebergs. The manual plot was updated twice daily. The plot was used by the Ice Patrol personnel to help determine if an iceberg report was a new sighting or a resight of an iceberg already being monitored. Lenczyk (1964) published a method of predicting the deterioration of icebergs that was used by Ice Patrol up until 1983. The method used sea surface temperature and iceberg size as its inputs to predict, in an average sea state, the number of days for an iceberg to melt. The deterioration was done twice weekly and records for each iceberg were kept by hand. The sea surface temperature was obtained from charts prepared by the U.S. Navy and updates provided by ships reporting sea surface temperature directly to Ice Patrol. This deterioration method was used as input by the Ice Patrol officer to decide to remove an iceberg from the active plot.

Modeling Of Iceberg Drift (1971-1979)

In 1971, Ice Patrol began using a computerized version of the manual vector addition routine. The program is described in Morgan (1971). The model area for the computerized vector addition routine was selected to cover the area from 40 to 52 degrees North and from 39 to 57 degrees West. At the time of the model creation, it was felt this area would allow modeling of nearly every iceberg that would create a threat to navigation within the area of Ice Patrol's statutory responsibility.

A computerized version of the monthly currents field was created from the same data Ice patrol had been using as the input to the manual vector addition method. The current fields were updated by Scobie and Schultz (1976) by incorporating recent survey information into the monthly means.

FNWC provided a computer-readable wind input for the computer model on a one-degree latitude by two-degree longitude grid covering the model area. Analysis winds along with predicted winds 12 hours, 24 hours, and 36 hours into the future were provided. This allowed Ice Patrol to be able to predict iceberg movement for periods up to 36 hours into the future.

The computerization of the manual vector addition routine helped eliminate cumulative errors associated with hand plotting. The computer also allowed all iceberg reports received within the model region to have their drift predicted without adding much workload to the Ice Patrol staff. The introduction of the model provided a better tool to determine whether an iceberg sighting report was either a new iceberg or a report of an iceberg already being monitored. This improved ability to model all icebergs and determine if the report was for a new iceberg or not helped improve the accuracy of the estimate made by Ice Patrol of the number of icebergs crossing south of 48 North. Icebergs which were drifted south of 48 North by the model without actually being seen were included in the estimate of icebergs crossing 48 North.

Modeling Of Iceberg Drift (1979-Present)

In 1979, the vector addition computer program was replaced by a dynamical balance of forces model (Mountain, 1979). The input procedures, the appearance of the model output, and the model area did not change with the model replacement. The winds used as the new model input were supplied by FNMOC. The monthly sea current files were combined into a single mean historical current field and used as the current input into the new model (Murray, 1979). In 1981, an addition was made to the model to allow the mean current field to be modified by real time satellite tracked drifter data (Summy and Anderson, 1983). The addition of real time current data allowed the drift prediction model to produce better results. ln l982, a computerized deterioration prediction model was implemented (Anderson, 1983). The deterioration model allowed the melting of all the icebergs being tracked by IIP to be predicted, not just the icebergs done by hand close to the limits of all known ice.

During the active season, sighting reports received in the area where no model ocean current data exists (along the coast and in the bays of the Newfoundland coast) are not entered into the model. Only a small percentage of the icebergs reported in the Avalon Channel (the area just off the east coast of Newfoundland) are entered into the model.

Icebergs in this area, although south of 48 North, do not affect the limits of the area of iceberg danger. The total number of iceberg sighting reports received and not entered into the model for this area (and therefore the data base) is unknown.

Analysis Techniques Of Sighting/Drift Data:

All iceberg sighting data received by Ice Patrol is treated the same regardless of sighting source. After a sighting report is received, Ice Patrol personnel must determine whether the report is for a new iceberg or are sight of an iceberg already reported. The reported position is compared to the predicted positions of previously reported icebergs.

The criteria for determining whether a sighting report is a resight or not have changed over the years and also vary by geographic position within the Ice Patrol area and with proximity to the limits of all known ice. The criteria described below are the general principles used from 1960 to 1991.

It the report is in an area known to have variable currents (particularly near the Tail of the Banks), a sighting report within about 30-40 miles (depending upon when the iceberg was last reported) of the predicted position of a previous report could be considered a resight. Icebergs further from the limits of all known ice are more likely to be resighted, particularly those on the northern portion of the Grand Banks.

As the "Limits of all known ice" (LAKI) are approached, a more conservative approach to resights is taken. Unless the sighting report closely approximates the predicted position and size of a previous report, the iceberg is added rather than resighted. This philosophy ensures all of the icebergs near the limits of all known ice are reported in Ice Patrol's products.

There are four ways icebergs are removed from the list of active icebergs being monitored by Ice Patrol. If an Ice Patrol flight over flies the location of an iceberg and the iceberg is not located, the iceberg will be deleted from the active iceberg list. If the iceberg is predicted to have melted, it will be removed from the active list. A more conservative approach to removing icebergs because of melt is applied when the iceberg is close to the limits of all known ice. If an iceberg has been on the active list for thirty days without been resighted, it will be removed. If an iceberg is predicted to drift to the east or west of the Ice Patrol area, it will be removed from the list of active icebergs and a note about the last predicted position will be put in the iceberg bulletin sent to shipping.

Icebergs are not removed from the active list when a ship report of no ice in an area is received because the errors associated with the drift prediction could easily have placed the iceberg outside the detection capability of the ship.

"Counting" The Icebergs South Of 48 North

From 1960 to 1988, the estimate of icebergs crossing south of 48 North was determined by hand counting from the paper records and/or model outputs. The Ice Patrol officer was responsible for determining the estimate of the number of icebergs crossing 48 North, a task that was easier in light ice years than during heavy years.

"Counting" The Icebergs South Of 48 North (1960-1970)

A technician was assigned to keep track of the number of iceberg sightings that were reported south of 48 North. Icebergs that were predicted to drift south of 48 North were also included. In heavy ice years, not all of the icebergs reported may have had the manual drift done. The numbers produced by the technician were reviewed by the Ice Patrol officer prior to release.

"Counting" The Icebergs South Of 48 North (1970-1988)

For the computer model years, the technician would review the daily model printouts each month and determine which icebergs had either been sighted or drifted south of 48 North. No differentiation was made between icebergs sighted and those drifted south of 48 North (without actually being seen south of 48 North). For each iceberg south of 48 North, the technician would have to determine how many icebergs that model entry represented. (When IIP received reports with multiple icebergs in the same location, only one entry would be made into the model and the number of icebergs that entry represented would be noted in the model input log.) The technician would also ensure that the target number was not included in last month's count. The number of chances for errors within the manual counting scheme increased with the number of icebergs entered into the model. Beginning in 1982, the computer model used by International Ice Patrol created a file containing the sighting and final drift position for each sighting entered into the model. Only sighting reports received by Ice Patrol with positions within the bounds of the model (40 to 52 North and 39 to 57 West) were entered into the model. This means all sighting reports after 1982 outside the bounds of the model are NOT included in the database. The number of reports received outside of the model area is estimated to be less than 100 per year with the majority of the reports being north of 52 North. After 1982, sighting reports received when the model was not being run are not included in the database.

"Counting" The Icebergs South Of 48 North (1989-1991)

Development of a computerized technique to "count" the number of icebergs crossing 48 North began in 1989. This method was used to generate the numbers published in the 1989 to 1991 bulletins. Development was completed in 1991. The new technique takes into account the number of icebergs each entry represents and provides a break down by sighted versus drifted but never sighted south of 48 North. The new computerized technique uses the model iceberg sighting history file. This file contains the sighting date and position, and final drift position for each target entered into the model, including resights. The counting program examines all of the entries for each target number that was an iceberg (not a radar or growler) to see if: (1) an iceberg entry was sighted south of 48 North or (2) if an entry was drifted south of 48 North without being sighted south of 48 North.

A "Count" Review

A summary of the iceberg sightings from the database for the period 1960 to 1981 is shown in Table 1. Also included in Table 1 is the estimate of the icebergs to have crossed south of 48 North for each year. In comparing the data base summary to the published estimate of icebergs drifting south of 48 North, some observations can be made.

In 1966, Ice Patrol published an estimate of zero icebergs drifting south of 48 North yet the database includes 12 iceberg reports representing 14 icebergs sighted south of 48 North. No explanation for this observation is offered.

In 1969, 1979, 1980, and 1981, the number of icebergs represented by the data base iceberg sighting reports sighted south of 48 North is less than the published estimate of the number of icebergs drifting south of 48 North. A possible explanation for this observation would be the inclusion in the published estimate of icebergs predicted to have drifted south of 48 North by the prediction scheme used during those years. In 1960 through 1964, the number of icebergs represented by the database sighted south of 48 North is larger than the published estimate of the number of icebergs drifting south of 48 North. This could be accounted for by the resighting of icebergs already reported and regular reconnaissance flights of the same area.

The new computerized counting technique was applied to the model iceberg sighting history files from 1982 to 1991. A summary of this application is in Table2. For the period 1982 to 1984, the sighting source was not entered into the model. For the period 1982 to 1985, the number of icebergs each entry represented was not entered into the model. The new computerized counting technique was applied consistently to all of the data. The results show differences with the previous methods used. The computerized technique is believed to be a more accurate reflection of the icebergs WHICH IIP INCLUDED IN ITS MODEL that were either sighted south of 48 North or drifted south of 48 North.

Summary

The IIP iceberg-sighting database is not a complete set of all icebergs actually drifting south of 48 North each year. Although not complete, the Ice Patrol database does represent the most complete and continuous iceberg data set available.

Over the past 30 years, numerous changes have occurred that effected Ice Patrol's ability to estimate the number of icebergs crossing 48 North. As the people at Ice Patrol changed, the methods used to accomplish manual tasks changed (Examples: determining if a report is a resight of an iceberg already being drifted and performing the annual counts). Technological advances affected, and continue to affect, Ice Patrol's operations and thus the gathering and processing of data. Bursts of activity in the Ice Patrol area by outside concerns (oil industry, fishing industry, and government agencies) provide increases in the volume of data to be processed. All of these factors have significantly affected icebergs crossing 48 North and make difficult direct year-to-year comparisons.

Several efforts have been made by a variety of authors to use different methods to classify/rank the severity of a year with regards to icebergs. Although these methods are all based on the estimates of icebergs crossing48 North, the methods do not use definitive numbers as a measure. In 1987, Ice Patrol began classifying season severity (Alfultis,1987). Ice seasons are classified as light (less than 300 icebergs estimated south of 48 North), intermediate (between 300 and 600 icebergs estimated south of 48 North), heavy (between 600 and 900 icebergs estimated south of 48 North), or extreme (more than 9OO icebergs estimated south of 48 North). Prior to 1987, the ice seasons were classified by Ice Patrol as light, normal, or heavy by comparing the annual estimate of the number of icebergs crossing 48 North to the long-term average. Davidson et al. (1986) describe a severity ranking system they used in their work with the data set. This system relies on relative comparison of seasons.

Hopefully, this Paper has provided enough insight into the Ice Patrol iceberg database to allow it to be used within its collection constraints by others.

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Operational Changes since 1991

In the early 1990's, Forward Looking Airborne Radar (FLAR) was used with IIP flights. FLAR enabled IIP to further discriminate between icebergs and ships. In 1995, this allowed IIP to increase flight track spacing from 25 nautical miles to 30 nautical miles and still maintain 200 percent coverage.